6. (New) The method of claim 5 wherein the pulses are in the Terahertz band.

7. (New) The method of claim 5 wherein the step of transforming comprises directing the beam into a wave-guide structure having suitable geometric configuration and dielectric/metal properties.

8. (New) The method of claim 2 wherein said manipulating means is a deflector, which is driven by small voltage.

REMARKS

Claims 1 is pending in this application. The specification, drawings and claims have been objected to and claim 1 has been rejected. However, upon entry of the amendments to the claim and acceptance of the substitute specification and drawings, it is respectfully submitted that this application will be in a condition to be allowed. Review and reconsideration of this application are therefore respectfully requested.

Oath or Declaration

The Office Action has required a new oath or Declaration, which is submitted herewith. Entry is respectfully requested.

Objections

The Office Action objects to the specification, drawings and claims. Applicant submits herewith a substitute specification. Applicant has reviewed the specification and corrected various grammatical and typographical errors. No objectionable new matter is inserted. Entry of these amendments via acceptance of this substitute specification is hereby respectfully requested.

The Office Action has objected to the drawings as not fully showing every aspect of the claimed invention. Applicant submits herewith-revised drawings that correct this perceived deficiency. The specification has been amended to describe these drawings. It is respectfully submitted that no new matter has been inserted, since the drawings formed part of the original disclosure and the description has been incorporated from the parent of this continuation-in-part application. Entry of these drawings into the application is therefore respectfully requested.

Claim Rejection 35 U.S.C. § 112

Claim 1 has been rejected under 35 U.S.C. § 112, second paragraph as being indefinite. This reason for rejection is respectfully traversed. Applicant has re-written claim 1 to distinctly point out and claim the present invention in a manner compliant with the statutory requirements. Withdrawal of this reason for rejection is therefore respectfully requested.

Claim Rejection 35 U.S.C. § 102

Claim 1 has been rejected as being anticipated by U.S. Patent No. 6,448,850—Yamada. This reason for rejection is respectfully traversed. The fundamental difference between the present invention and Yamada is that the present invention does not employ continuous wave generation, but instead produces electromagnetic pulses, preferably by the periodic switching of the presence and absence of an electron beam in an exchange zone. Thus, in certain embodiments, the present invention preferably employs a pair of electrodes which, although disclosed in Yamada are used therein to stabilize the position of the electron beam during its passage through vacuum-dielectric channel, rather than generate a periodic pulse, as required by claim 1 as amended. In Yamada, the electrodes are located along the entire pathway and they have a length the same as that of the channel; the electrodes bound entire zone of energy exchange. In contrast, in the apparatus of the present invention, the pair of electrodes periodically deflect an electron beam from a zone of energy exchange; the electrodes are located before the zone of exchange. Moreover, in certain embodiments, the present invention can operate without involving the pair of electrodes at all – the alternative approach for deflection of an electron beam comprises a magnetic deflector. Such an alternative is not disclosed or suggested in Yamada.

The production of a periodic pulse in accordance with the present invention requires a "metal-dielectric structure" as disclosed and claimed. Essentially, to exploit the Smith-Purcell effect, transition radiation, diffraction radiation and/or their combinations as described in the specification to produce periodic pulses the present invention deflects the electron beam from an interaction zone where an energy exchange exists. Yamada does not disclose the use of these effects to produce periodic pulses, either in addition to or in lieu of producing periodic pulses by electron beam deflection.

Because Yamada does not disclose or even suggest a producing of train of pulses initiated by a deflector which periodically directs and redirects an electron beam to a metal-dielectric structure

of general type, as now claimed in claim 1, claim 1 is not anticipated and this reason for rejection should be withdrawn.

Double Patenting Rejection

Claim 1 has been provisionally rejected as being unpatentable over claim 1 of co-pending Application No. 10/447,869. This reason for rejection is respectfully traversed. In view of the amendments set forth above and the argument set forth with respect to Yamada, it is respectfully submitted that forming periodic pulses in the manner claimed is patentably distinct from the subject matter of over claim 1 of co-pending Application No. 10/447,869. Withdrawal of this reason for rejection is therefore respectfully requested.

Conclusion

For all these reasons, it is respectfully submitted that the present application, including the amendments set forth above and the additional materials submitted herewith, is now in a condition to be allowed. Notice to this effect is earnestly solicited.

Respectfully submitted,

Albert T. Keyack

Albert T. Keyack
Reg. No. 32,906
Attorney for Applicant
(215) 738-5925

Dated: March 29, 2005

Art Unit : 2873
Examiner : David N. Spector
Serial No. : 10/723,060

CLAIMS INCORPORATING AMENDMENTS

1. (Currently Amended) An apparatus for producing a sequence of terahertz electromagnetic pulses by a driven particle beam comprising an electromagnetic beam is transmitted into a metal-dielectric structure whereby said electromagnetic beam partially transforms into a delayed electromagnetic wave, and a beam of charged is transmitted to said structure, and periodically deflected away from it and back, whereby the kinetic energy of the charged particles periodically transforms into energy of the delayed electromagnetic wave having the same phase-frequency's characteristics as transformed field of the electromagnetic beam, whereby the transformation of the electromagnetic beam and excitation of the electromagnetic wave by the beam of charged particles takes place within a defined spatial region, wherein said spatial region is localized within said metal-dielectric structure.

2. (New) The apparatus of claim 1 wherein the pulses are in the Terahertz band.

3. (New) The apparatus of claim 1 wherein said transforming means is a wave-guide structure having suitable geometric configuration and dielectric/metal properties.

4. (New) The apparatus of claim 1 further comprising a deflector which is driven by small voltage.

5. (New) Methods for producing periodic pulses of electromagnetic energy by accelerating charged particles so as to establish a positive net emission of electromagnetic radiation by providing a manipulating means for driving accelerated particles, a transforming means for transforming an initial electromagnetic beam into a delayed electromagnetic wave and converting the kinetic energy of the charged particles into electromagnetic energy of the delayed electromagnetic wave, wherein the steps of transforming and converting take place simultaneously in the same interaction region, which has been formed by a wave-guiding structure.

Art Unit : 2873
Examiner : David N. Spector
Serial No. : 10/723,060

6. (New) The method of claim 5 wherein the pulses are in the Terahertz band.

7. (New) The method of claim 5 wherein the step of transforming comprises directing the beam into a wave-guide structure having suitable geometric configuration and dielectric/metal properties.

8. (New) The method of claim 2 wherein said manipulating means is a deflector, which is driven by small voltage.

PTO/SB/01 (09-04)
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DECLARATION FOR UTILITY OR DESIGN PATENT APPLICATION (37 CFR 1.63)

Attorney Docket Number	Zhilikov-2
First Named Inventor	Zhilikov
COMPLETE IF KNOWN	
Application Number	10/723,060
Filing Date	11/26/2003
Art Unit	2873
Examiner Name	Spector

☒ Declaration Submitted With Initial Filing OR ☐ Declaration Submitted after Initial Filing (surcharge (37 CFR 1.16 (e)) required)

I hereby declare that:

Each inventor's residence, mailing address, and citizenship are as stated below next to their name.

I believe the inventor(s) named below to be the original and first inventor(s) of the subject matter which is claimed and for which a patent is sought on the invention entitled:

Terahertz and Mid-Infrared Probing Apparatus With High Repetition Rate Pulses and Methods of Using Same

(Title of the Invention)

the specification of which

☐ is attached hereto

OR

☒ was filed on (MM/DD/YYYY) 11/26/2003 as United States Application Number or PCT International Application Number 10/723,060 and was amended on (MM/DD/YYYY) ______ (if applicable).

I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims, as amended by any amendment specifically referred to above.

I acknowledge the duty to disclose information which is material to patentability as defined in 37 CFR 1.56, including for continuation-in-part applications, material information which became available between the filing date of the prior application and the national or PCT international filing date of the continuation-in-part application.

I hereby claim foreign priority benefits under 35 U.S.C. 119(a)-(d) or (f), or 365(b) of any foreign application(s) for patent, inventor's or plant breeder's rights certificate(s), or 365(a) of any PCT international application which designated at least one country other than the United States of America, listed below and have also identified below, by checking the box, any foreign application for patent, inventor's or plant breeder's rights certificate(s), or any PCT international application having a filing date before that of the application on which priority is claimed.

Prior Foreign Application Number(s)	Country	Foreign Filing Date (MM/DD/YYYY)	Priority Not Claimed	Certified Copy Attached? YES	NO
			☐	☐	☐
			☐	☐	☐
			☐	☐	☐
			☐	☐	☐

☐ Additional foreign application numbers are listed on a supplemental priority data sheet PTO/SB/02B attached hereto.

PTO/SB/01 (09-04)
Approved for use through 07/31/2006.OMB 0651-0032
U.S. Patent and Trademark Office;U.S. DEPARTMENT OF COMMERCE

DECLARATION — Utility or Design Patent Application

Direct all correspondence to:	☐ The address associated with Customer Number:		OR ☐ Correspondence address below
Name			
Address			
City	State	ZIP	
Country	Telephone	Fax	

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under 18 U.S.C. 1001 and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

NAME OF SOLE OR FIRST INVENTOR:	☐ A petition has been filed for this unsigned inventor		
Given Name (first and middle [if any]) Stanislav	Family Name or Surname Zhilkov		
Inventor's Signature Stan Zhilkov			Date March 2, 2005
Residence: City Philadelphia	State PA	Country USA	Citizenship Ukrainian
Mailing Address 12030 Bustleton Ave			
City Philadelphia	State PA	Zip 19116	Country USA
NAME OF SECOND INVENTOR:	☐ A petition has been filed for this unsigned inventor		
Given Name (first and middle [if any])	Family Name or Surname		
Inventor's Signature			Date
Residence: City	State	Country	Citizenship
Mailing Address			
City	State	Zip	Country

☐ Additional inventors or a legal representative are being named on the ______ supplemental sheet(s) PTO/SB/02A or 02LR attached hereto.

TERAHERTZ AND MID-INFRARED PROBING APPARATUS WITH HIGH REPETITION RATE PULSES, AND METHODS OF USING SAME

This is a continuation-in-part of co-pending U.S. Patent Application Serial Number 10/447,869 filed May 29, 2003, which is incorporated herein by reference as if fully set forth.

The present invention is directed to improved laser systems, and in particular, methods ~~and apparatus~~and apparatus for both the imaging an internal media for studying objects, e.g., medical imaging, and external probing of pre-surfaces region for studying objects, e.g., radar and the like.

~~The invention provides methods for producing and using terahertz or infrared pulses by accelerating charged particles so as to establish a periodic positive net emission of electromagnetic radiation. In accordance with the invention the method comprises the a manipulating means for driving accelerated particles, a transforming means for transfiguration attaining the transformation of an initial em beam into a delayed electromagnetic wave and also to provide a means for converting the kinetic energy of charged particles into an energy of the same delayed electromagnetic wave. The steps of transfiguration transforming and converting take place simultaneously in the same interaction region, which has been formed by a wave-guiding structure. Said transforming means may be implemented, e.g., as said wave-guiding structure having a suitable geometric configuration and dielectric/metal properties. Said manipulating means may be implemented, e.g., as a deflector, which is driven by small voltage; alternatively, a "buncher" or other charged particles beam's properties changing system can be used for said manipulation.~~

~~Exploitation of the pulses is permits them to be directed as a sequence of pulses into the object or media being studied and analyzing the data. The pulses are detected by detecting means~~

~~after passing the sequence through the object. Alternatively, data can be collected and analyzed by detecting means that register the pulses redirected (e.g., reflected, refracted, scattered, etc.) from the object or media being studied.~~

BACKGROUND OF THE INVENTION

~~1. General State of the Art~~

Vacuum electronic devices are successfully operating up to 100 GHz (wavelengths of approximately 3 mm and higher). For example, research groups ~~, which~~ that develop the high power generators of the Giroklystron ~~type,~~type demonstrated significant progress during past several years. Optical range for these devices is up to the near-infrared band (wavelengths ~10 micron and less; frequencies ~ 30 THz and more) and they use solid-state devices including semiconductor lasers and gas powerful lasers for wave generation. The terahertz (THz) band of the electromagnetic ~~(E-M)~~ spectrum exists between the mid-infrared band and the microwave band. Loosely defined, the terahertz band encompasses that part of the frequency spectrum that includes the frequencies ranging from about 0.3-10.0 THz, or equivalently, the wavelengths ranging from about 1.0-0.03 millimeters. In the art, the terahertz band is also known as the far-infrared band or the sub millimeter band.

The terahertz band is one of the last spectral regions where compact, powerful, coherent sources are available. High-performance terahertz-ray systems, such as periodically-probing sensors or fast-made imaging ~~systems,~~systems need robust pulsed terahertz-ray sources having tunable, precision narrow-band, low cost means for driving the radiation power. THz (or far-infrared, or sub millimeter) and mid-infrared (3.0 – 30.0 micron) wavelength ranges are of interest both for quantum electronics ~~developers~~ and vacuum electronics developers ~~ones~~, because ~~of~~there exists a- lack of devices and systems that can effectively utilize these frequencies for scanning or imaging. Although the THz range is important for both civilian and military applications~~.~~, there has as of yet been little implementation, however, since in many cases such applications require producing radiation having the form of a sequence of pulses with high repetition rate.

~~2. Quantum Electronics Devices~~

Common quantum electronics methods for the generation of mid-infrared (IR) or THz radiation are mostly based on high-energy, ultra-short laser pulses, which ~~take~~ direct irradiating influence either on unbiased or biased solid-state (semiconductor or nonlinear) crystals. ~~Also,~~ THz emission from unbiased helium gas has been reported ~~[1]~~ and the first demonstration of the generation of THz radiation by photo-ionization of electrically biased air with high-energy fs-pulses ~~was~~has been -presented ~~[2]~~.

Until recently, only thermal incoherent solid-state optical sources emitted a significant amount of light in the mid-infrared or terahertz band of the frequency spectrum. Within the last few years, several types of solid-state THz coherent optical sources have been developed for pulsed and continuous-wave applications. These THz coherent optical sources include direct coherent sources (DCS), electronically mixed electronic oscillators (EMEO), electronically mixed optical oscillators (EMOO), and optically mixed optical oscillators (OMOO). In the most successful of today's case for affordable THz crystal-emitted coherent light sources, the output power is less than 10 microwatts, while ~~a~~ the laser pump power ~~of~~is about 0.1 – 1.0 W ~~[3]~~. Pump lasers have been demonstrated that produce initial radiation in the form of pulse having duration from ~ 1 nanoseconds to ~ 0.1 picoseconds, at ~~that,~~which the repetition rate for such pulses is usually ~~equal to~~ about 1 kHz ~~[4]~~. One-time pulsing pump lasers having an integration time of ~ 10 s were the first in use, while the THz signals with working at full repetition rate 64 MHz are known in the art~~has also been observed [5]~~.

~~3. Relativistic Vacuum Electronics Devices~~

THz radiation (as it shown by quantum systems' uses) can be initiated by a laser's fast pulse, and alternatively can be initiated by short relativistic electron "bunches" that produce terahertz Smith-Purcell (SP) radiation, terahertz Cherenkov radiation or terahertz wake fields – such emission takes place into the particle accelerating structures ~~[6,7,8]~~. The idea to use the radiation of fast moving electrons has been recognized by vacuum electronics developers, who try to implement an accelerator approach into a traditional microwave electronic scheme for making a workable wavelength shorter, up to a level that produces terahertz-rays. In this manner, prior art devices such as the so-called Submillimetre-Wave Reflex Klystron ~~[9]~~, 1200 GHz Nanoklystron ~~[10]~~ and several other vacuum devices ~~[11,12]~~ have been developed during recent years.

Also, there has been recent progress ~~into~~ the development of the vacuum tube type Generators of Diffractive Irradiation (GDI) moving toward THz region ~~[13]~~ as well as ~~into~~ the development of ~~very~~ similar devices, such as the Smith-Purcell Free Electron Laser ("SP FEL")~~[14]~~. Initially GDI ~~was~~ were ~~in~~ used in the millimeter band, while SP FEL had been designed for infrared band, especially. GDI and SP FEL might be joined into one generating type with near-field Cherenkov generator ~~[15],~~ because all these devices use a resonance surface mode for energy exchange between relativistic electrons and a terahertz-wave. All generators of this type are called as Over-Light Speed Effect (OLSE) devices. OLSE devices (e.g., Smith-Purcell, or Cherenkov, or Diffractive, or so-called Transition Radiation ~~[16]~~) of any kind consists of charged particle radiation, when the velocity of ~~particle~~a moving particle is higher than the speed, with which the front of electromagnetic wave is transferred (i.e., higher than the phase speed of light). Regular Free Electron Lasers (FEL), having the necessary ~~undulator~~ wave generator with a very high magnetic field of sophisticated configuration are rather expensive, but SP FEL or GDI devices does not require use of such a field. Also, a regular FEL is of much larger physically as compared with GDI/SP FEL.

Klystron type generators as well as regular FELs can emit a sequence of THz pulses. For this purpose a special cathode or electron gun ~~should be used~~is used, which produces a sequence of the electron bunches. However, producing of these bunches is also rather expensive, while the repetition rate for THz pulses has not to date achieved high value in any of such generators.

Thus, although there have been advances in the prior art, to date, a system that is both robust and cost-effective has not been created. It has now been found that t~~T~~he current of an electron beam, which is needed ~~for~~ to form ~~ing the~~ pulses into OLSE ~~-schemes~~devices, and a robust repetition rate, which can be reached, ~~are quite appropriate to be realized and detected by~~ can be created in accordance with the system of the present invention while utilizing technology known in the art, as demonstrated below.

SUMMARY OF THE INVENTION

The present invention provides methods for producing and using terahertz or infrared pulses by accelerating charged particles so as to establish a periodic positive net emission of

electromagnetic radiation. In accordance with the invention the method comprises the a manipulating means for driving accelerated particles, a transforming means for attaining the transformation of an initial em-beam into a delayed electromagnetic wave and also to provide a means for converting the kinetic energy of charged particles into an energy of the same delayed electromagnetic wave. The steps of transforming and converting take place simultaneously in the same interaction region, which has been formed by a wave-guiding structure. Said transforming means may be implemented, e.g., as said wave-guiding structure having a suitable geometric configuration and dielectric/metal properties. Said manipulating means may be implemented, e.g., as a deflector, which is driven by small voltage; alternatively, a "buncher" or other charged particles beam's properties changing system can be used for said manipulation.

Exploitation of the pulses is permits them to be directed as a sequence of pulses into the object or media being studied and analyzing the data. The pulses are detected by detecting means after passing the sequence through the object. Alternatively, data can be collected and analyzed by detecting means that register the pulses redirected (e.g., reflected, refracted, scattered, etc.) from the object or media being studied.

~~4. Comparison of threshold current into GDI, SP FEL and Grating Cherenkov schemes~~

First, GDI was simultaneously developed with Orotron four decades ago and had very similar design. Many kinds of GDI have been proposed ~~by Shestopalov's group [17,18,19,13],~~ including metal grating on metal slab, metal grating on dielectric slab, dielectric grating on metal slab, GDI with several gratings, GDI with several electron beams, etc. Workable ideas for all of these devices consists ~~in~~ of an exploitation of the energy exchange between the electron beam and the irradiated field, at ~~that~~which~~,~~ the exchange is provided through electromagnetic surface wave (ESW), which takes place into small spatial region near the grating.

An SP FEL, which had subtle a difference with one-beam metal grating GDI has also been demonstrated~~, was experimentally studied by Walsh and Brownell [20,21,14]~~.

The simplest analytical expression, which satisfactorily describes a metal grating GDI or an SP FEL, ~~has been received by Kim and Song [22]. They have obtained~~ is a formula for growth rate "μ", which can be written as:

$$2\mu=(4\pi/\beta\beta/\gamma\gamma)*SQRT(exp2*EM)*SQRT((i/I)/(\lambda*W)) \quad (F1),$$

where "β"=v/c;

"c" is speed of light;

"v" is the velocity of electron cp-beam, which equals to phase speed of evanescent mode ESW;

γ - is the relativistic factor of electrons in cp-beam;

"λ" is wavelength of initial em-beam's field in free space;

"h" is the dimension of electron cp-beam in x direction (half-thickness); $h \ll \lambda$;

"W" is the dimension of electron cp-beam in y direction (width);

"b" - is the height of passing of electron cp-beam over the grating surface;

"l" is longitude of space in z direction, where electron cp-beam interacts with ESW of em-beam;

"i" is electric current of the cp-beam;

"I"=17kA is the Alfven current;

$exp2=exp(-(4\pi/\beta\gamma)*(b/\lambda))$;

EM – is the element of a refraction matrix of the metal grating, which provides the "quality" of coupling between electromagnetic field and electron cp-beam. In the optimal case ~~Kim~~ this formula takes exp2*EM=~0.1. ~~Kim's theory is~~ and has satisfactory correspondenced with most experimental data.

~~Khizhniak and Zhilkov have studied and patented the~~ A device~~,~~ is also known which uses ESW over the dielectric grating in the case of total internal reflection ~~[23,24,25]. They found so-called~~ using a resonance transformation of a spatial wave into ESW by ~~such~~ a Grating Cherenkov Scheme (GCS)~~.~~ described by a ~~For GCS can be used~~ formula, which is similar to (F1), but EM ~~should be~~ is changed ton ED – the element of ~~a~~ refraction matrix of the dielectric grating. In the optimal case ED can reach ~1.0, ~~e.g.~~ i.e., the "quality" of the coupling between electromagnetic field and electron beam over the dielectric grating can be up to several times more~~,~~ than over the metal grating. The ~~M~~main reason~~,~~ which explains this fact, is ~~following:~~ that GCS uses a single mode regime of field versus two modes regime (at least) in metal grating GDI/SP FEL.

Analysis of threshold currents for metal grating GDI/SP FELs is made in the numeric example, when kinetic energy of electrons is equal to 32keV and ~~;~~ phase velocity of ESW is equal to

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β=v/c=0.34 ~~in this case~~. Longitude of the interaction region "l" is squeezed up to the accessible limit, which ~~. Limit~~ is determined by the minimum ~~as~~ possible ~~of~~ diameter of gauss optical beam and equals to ~~couple~~ multiple of tens of optical wavelengths, e.g., l=10mλ, where m – is a small integer. It is necessary for modulation to reach the growth of intensity of optical beam up to 100a percents after passing through the interaction region; a – is a small rational number, i.e., a<<1 and it is ~~supposed~~ typically ~~to be~~ 2μl=a. If the electron beam is squeezed up to h=0.1λ and W=100h=10λ, and the "quality" of coupling between optical field and electron beam is optimal, then from (F1) the formula for necessary current in GDI/SP FEL is approximately obtained as i=1.78a*a/(m*m) Amp. As it's seen from this formula the 13% gain (a=0.13 is enough for smooth modulation purpose) after passing l=30λ (e.g. m=3) will be reached, if GDI/SP FEL has a current i=3.3 milliamp. So, the necessary current of a metal grating GDI is approximately equal to necessary current of SP FEL~~,~~; however, at the same time the necessary current of resonance GCS is significantly less (~0.3 milliamp), because an optimal GCS has the best "quality" of coupling between the optical field and the electron beam.

Of course, for the forming ~~of~~ pulses ~~a deep of~~ the -modulation should be greater than in mentioned-above numerical example. It means that a case where a=0.13 is not enough for pulses forming, but it should instead be a case where ~~be equal to~~ a=0.90, approximately. For last case the numerical calculation of the necessary threshold current is much more difficult~~,~~ than in the case of smooth modulation, but the same conclusion is true: the calculated necessary current, which is needed for forming pulses by resonance GCS, is considerably less than calculated threshold current of metal grating GDI/ SP FEL. However, ~~recently gotten Brownell's experimental results show~~ it is known in the art that the generation process by SP FEL is started for a threshold current, which is three times less, than Kim's theory or any other theory predicts. So, both GCS and GDI/SP FEL might be considered useful for purpose of effective forming the THz pulses by a scheme having reasonable value of electron current.

~~5. Achievable repetition rate for OLSE schemes~~

The time of interaction between transformed em-beam field and electron cp-beam approximately equals t=l/v=10m*λ/(βc)=10m/(βω), where ω is a frequency of field of em-beam. Consequently, the frequency of modulation of em-beam by electron beam can approximately reach:

$$\Omega=1/nt=\beta\omega/10nm \qquad \text{(F2)},$$

where "n" is the so-called coefficient of packing, which shows the ratio of a rather long non-modulated (or without-pulses) period to the time of interaction (when pulse is sharply appeared, existed and decreased). To be ~~sure in our~~ verify these results, we can rewrite:

$$\Omega < \Omega R \sim 0.001\ \omega = 0.1\ \%\ \omega \qquad \text{(F3),}$$

where ΩR is the robust maximum of frequency of modulation~~;~~ which can be reached.

The using of formula (F3) for ΩR means that, for example, 1 THz continue wave beam might be separated into the sequence of t-pulses with repetition rate equaled to 1 GHz, while for mid-infrared case having λ=30 micron (or ω = 10 THz) it might be achieved the sequence of quasi-pulses with repetition rate near 10 GHz. Both 1 GHz and 10 GHz are quite appropriate repetition rate to be registered by the fastest modern detectors of THz radiation ~~[26,27]~~.

As it follows from F2, the theoretically predictable absolute maximum for repetition rate ΩA might be calculated, if β = 0.9, m = 1 and n = 2 (relativistic electron beam is used for modulation, while optical beam is squeezed up to 10 λ and the without-pulses period is equal to a time of interaction). Such ΩA approximately defines as ω / 20 and equals up to 500 GHz for mid-infrared region. However, the registration of so fast 500 GHz repetition rate is not achievable by mid-infrared detectors, which have been developed until now~~.~~

DESCRIPTION OF THE PREFERRED EMBODIEMNTS

An ~~E~~effective manipulating means can be implemented into OLSE emitting scheme and this way the ultra-high repetition rate sequence of THz pulses can be formed.

~~1. Modulating process~~

In the case of using of ESW, the interaction region has effective longitude "l" and height ~(b + h), at ~~that~~which~~,~~ interaction takes place exactly at the time~~,~~ when the optical field, which should be modulated, and the electron beam, which provides modulation, are simultaneously present at said region. Controlled modulation of the optical field is able to be reached by changing ~~of~~the parameters of the interacting electron beam. In particular, before the process of interacting

~~process~~ the electron beam is able to be changed by at least two methods~~at least~~: 1) by bunching (making discrete density) of electron beam without changing ~~of~~ its propagating direction; and 2) by deflection of the electron beam from interaction region and returning to said region without changing ~~of~~ the current density.

———As far as first method is concerned, today's FEL / Particle Accelerator technique operates by relativistic flat electron bunch having parameters, for example, such as h=0.5μm, W=50.0μm, l=30μm, and i =100kA; ~~also it was recently reported about squeezing of~~ as known in the art, an electron bunch can be squeezed up to a value of h ~ that is approximately ~~some~~ tens of angstrom and a value of l/c ~~—some~~ that is approximately tens of an atto-second. Such bunching is over and above, than ~~it~~ what is neededs for optical modulation, ~~but~~however ~~the~~ making ~~of~~ such a bunch is very expensive ~~in~~ at the present time.

———As a second method, it is can be shown that a simple pair of flat electrodes is able to provide the necessary deflection/returning of the electron beam by using a voltage not very much more than ~1V. It ~~'~~is well-known if the axis of the electron beam is in the middle between two parallel flat electrodes when said electrodes have no voltage, than the switching on voltage "U" provides deflection of electron beam, ~~at that~~ which, in beginning of observation region said deflection "d" is proportionally $d \sim (U/\gamma/\beta\beta)*L1*(0.5L1+L2)/R$, where L1 is length of electrode, L2 is a distance from electrode to observation region, R is a distance between electrodes. So, if a pair of deflecting electrodes~~' pair~~ is interposed before interaction region (which coincides with observation region) and, for example, β=0.34, L1=30λ, R=4h=0.4λ, L2=m2*10λ, m2 is integer, than d is approximately equal $d=1.25*(1.5+m2)*\lambda*abs(U)/100$, where abs(U) is absolute value of U and U should be taken in volts. Taking m2=7 previous formula gives $d=0.1*abs(U)*\lambda=abs(U)*h$ and it shows the possibility of a simple system for manipulating ~~of~~ an electron beam ~~presence~~ into an interaction region. Said manipulating is ~~reached~~ preferably achieved by a small voltage, because if electron beam is deflected up to some "h" superfluously over conducting ESW surface, then interaction practically ceases. Hence, the changing of deflecting electrodes' voltage from zero to "U" leads to modulation of optical field and said modulation has the same frequency~~,~~ as the frequency of the voltage changing. Also for realizing ~~of~~ the second method, the deflector can be made as a standard ~~usual~~ magneto-deflecting system, which has a small manipulating magnetic field. Both a flat-electrodes deflector system and a magnetic one or, ~~maybe,~~ other similar deflecting systems do not have ~~some~~ problems in modern technical realization, and obviously, they won't be expensive.

If for modulating light producing a Smith-Purcell, or Cherenkov, or Transition Radiation effect, or any combination of OLSE effects are used, then the interaction region will be small as well as in previous example, and the simple manipulation by free moving electrons is going to provide the necessary modulation process, as ~~it~~ showns above.

~~2. Forming the sequence of pulses~~

~~The a~~Applying of a voltage from a saw-tooth oscillator to deflecting electrodes will provide predictable manipulation of the electron beam and this is the way the necessary sequence of pulses is formed. Having, for example, a periodically ~~working~~ energized 1 GHz saw-tooth oscillator, ~~it might be achieved~~ the same repetition rate is achieved for a formed sequence, while the irradiated field will be of terahertz band.

Such periodical driving means are ~~realized~~constructed at present, for example, in vacuum tube type electron guns, ~~which have been recently invented for~~found in ~~computers~~computer' monitors ~~[28]~~.

~~At that~~Therefore, two kinds of the forming of THz pulses should be separated from each other: 1) deep modulation of initial terahertz continueous wave; 2) directly producing ~~of the~~ terahertz- pulses' sequences without an initial continueous wave.

Referring now to the drawings, FIG. 1 is a schematic diagram of a preferred embodiment of the invention. The charged particle beam 1 is typically composed, for example, of electrons. Said beam is irradiated by the accelerating system 2, directed to the manipulating system 3, and after that directed to the transforming system 4. Optical beam 5, which should preferably be modulated, is also directed to the transforming system 4. Manipulating system 3 can be of bunching type, or of deflecting type (by electric field or by magnetic field, or by combination of such fields), or, may be of another type for changing the properties of the charged particle beam. Transforming system 4 can be of UOA type, or of FEL type, or of LAC type, or of other one from the full set of OLSE-type combinations. After passing through the transforming system 4 the modulated optical beam propagates in free space up to the distant detector 6; alternatively the

transforming system 4 turns into fiber optic transmitting line 7. Therefore, such a method of modulation can be exploited for both free space communication (when modulated laser beam 51 is transmitted, for example, directly to satellite receiver or retranslator) and for fiber optic communication (when modulated optical signal 52 is transmitted through a dielectric optical wave-guide).

Various changes to the foregoing embodiments of the present invention would now be evident to those skilled in the art. Accordingly, the particularly disclosed scope of the invention is set forth in the following claims. In view of the invention disclosed, the idea of the manipulation of an accelerated particle beam for creation controlled light modulators is quite workable now and can be realized in many different cases. As well as it is known said idea has never been published earlier, but modulators, which are based on this idea, will provide much more speed of modulation than previous ones. Additional reasons related to the usefulness of OLSE-modulator are disclosed herein. Nuclear weapons have for five generations been the main effect consisting in electromagnetic radiation (EMR). EMR is supposed to influence semiconductor elements the way that they will change their properties and after EMR influences the devices which contain said elements, the devices will typically malfunction. At the same time devices without semiconductor elements, for example vacuum tube type, do not malfunction after EMR influence. That's why the OLSE-type modulator, which does not have any semiconductor element, has a very important positive difference from electro-absorption modulators, which are made of semiconductor material.

FIG. 2 is a schematic diagram of a longitudinal section of a preferred embodiment. The ribbon electron beam 1 (e-beam) is preliminarily accelerated up to velocity $v/c=\beta$ and is directed to the manipulating element 12 which is preferably of the deflecting flat electrodes' type (deflector), which is separated by a distance L2 from the OLSE-transforming element 23 of the dielectric spatially periodical wave-guiding structure type (transformer). Deflector 12 and

transformer 23 are in a vacuum vessel 4 which is also illustrated schematically and is shown with a broken away portion allowing the components discussed immediately above to be viewed..

Having elliptical midplane the optical beam 5 (o-beam) with wavelength λ is normally directed to optical input surface 13 of transformer 23; at that, o-beam's electric field is parallel to the plane of longitudinal section. Transformer 23 is made of dielectric with refractive index n and has two surfaces – plane surface 13 for o-beam inputting and periodically ribbed surface 14 having period Λ; the angle between these surfaces is equal to α. At that, for optimal functioning two obligatory conditions must take place together:

$$\lambda/\Lambda = n * \sin(\alpha) = (c/v) > 1$$

E-beam is of ribbon type having small half-thickness h and width W, for example, W=100h, and β=0.34.

O-beam is supposed to have oval projection on the surface 14, for example, having longitude l=30λ. Deflector 20 consists of two flat parallel electrodes 21 and 22 each having longitude L1; the distance between said electrodes equals R, for example, R=4h. The applied voltage between the deflector's electrodes can be changed from 0 to U volts. If said voltage equals 0, then the e-beam moves in the middle plane between electrodes without deflection. If said voltage equals U, then the e-beam is deflected from said middle plane and the total deflection equals d after passing through the L1-length of deflector and L2-length between deflector and transformer.

When the e-beam passes thorough the deflector element 2 without deflection (voltage equals 0), then the trajectory 8 of e-beam is parallel to the ribbed surface 14 and has a height b over said surface. When the deflector's voltage equals U, then the trajectory 9 of the e-beam has a height not less than b +d over the ribbed surface 14.

If, for example, L1=30λ and L2=70λ, then d is approximately equal to d=abs (U)*h. Compared to non-deflecting trajectory 8, deflecting trajectory 9 of the e-beam has additional decreasing of coupling with the optical field, which is modulated, and said decreasing is in

proportion to exp ($2\pi d/\lambda\beta\gamma$). So, if, for example, d equals $d=0.1\lambda$ (i.e., U=1 volts and $h=0.1\lambda$), then in this example said coupling on the deflecting trajectory is up to six times less than coupling on the non-deflecting trajectory.

Ribbed surface 14, for example, has a ribbed profile; the dimensions of the ribs are determined to provide optimal value of the fundamental mode of a refraction matrix of said periodically ribbed surface. It is necessary for minimizing the value of current of e-beam, which is enough to provide modulation. However, even though the ribs have zero length and zero height (e.g., ribbed surface 14 is flat), then modulating effect can be reached too, but by using of considerably more value of the current of the e-beam than in the case of optimal profile. At that, the use of flat surface has important advantage – it is much more simple to go about making such a surface.

EXAMPLES

~~1. General definitions~~

A ~~S~~sequence of terahertz -pulses ~~might be used~~is useful -both for 1) the exploration of the internal media of ~~studying~~ objects and 2) the external describing of ~~studying~~ objects. In first case the pulses are directed into ~~studying~~an object and information is collected and ~~it has being~~ analyzed ~~the info, which is registered~~ the collection of data being performed by a detecting means after passing the sequence through said object. In second case, information is again analyzed by detecting means, ~~which register~~but in this case -the pulses that are collected are redirected from a surface of ~~studying~~the object being studied. The ~~F~~first-type of usage might be applicable for diagnost~~ics~~ing the characteristics of plasma, biomedical prob~~ation~~ing and ~~t-wave~~-imaging in security systems, while the second-type of ~~usag~~usage~~e~~ is typical for ~~radar's needs~~the needs of radar, sonar and similar systems. At the same time, both ~~types of~~ usages can be ~~realized~~ implemented for other practical applications including industrial process control, nondestructive testing and so on.

~~2. Diagnostics of plasma~~

It is known that for THz-frequencies the plasma acts as a nearly transparent dielectric, with refractive index close to unity. Analysis of the dispersion and attenuation of terahertz pulses

passing through studying media will enable properties of the plasma (collisional damping, electron density) to be characterized in an adequate manner ~~[29,30]~~.

———More comprehensive information might be received, if the high repetition rate sequences of terahertz pulses passing through plasma are analyzed.

~~3. T wave imaging for security systems~~

Imaging of terahertz radiation ~~or "T rays"~~ represents an emerging technology with significant potential for advanced, security-related inspection systems. ~~T rays~~ Terahertz radiation ~~are~~is transmitted by many visually opaque objects and materials but reflected by others, permitting complementary imaging in transmissive and reflective modes. Many potentially harmful gases and other chemicals exhibit distinctive spectral fingerprints in the terahertz region. Together these characteristics permit ~~T-ray~~ terahertz radiation-based discrimination between harmful and innocuous objects, materials, and chemicals concealed in packages and on personnel through the use of safe, low-power, non-ionizing radiation with no real or perceived health risks ~~[31]~~.

~~4. THz and mid-infrared radar~~

As noted above, ~~T~~the usage of high repetition rate sequence of ~~t~~ terahertz radiation -pulses opens ~~a~~the possibility ~~to~~of considerably improveing a radar system's sensitivity, target detection, discrimination and aimpoint selection ~~[32]~~. Such THz and mid-infrared radar related technologies and the associated processing techniques are useful both for military purposes and commercial ones.

~~5. Sensor for medical and bioscience applications~~

By combining the approaches ~~,~~ which have been ~~disclosed into three previous subsections,~~ above, those of skill in the art will appreciate that the present invention also provides a set of sensors for medical and bioscience applications ~~might be developed~~.

ABSTRACT

An apparatus for producing the sequence of Terahertz electromagnetic pulses by driven particle beam is disclosed. Initial electromagnetic beam (em-beam) is being sent to metal-dielectric structure the way that the field of said em-beam partially transforms into delayed electromagnetic wave, in preferred embodiment into the surface evanescent mode, and the beam of charged particles (cp-beam), in preferred embodiment electrons, is also being sent to said structure the way that the particles' kinetic energy partially transforms into energy of the delayed electromagnetic wave having the same phase-frequency's characteristics as transformed field of em-beam; at that, transformation of em-beam and excitation of wave by particles' cp-beam commonly take place at the same small space region, which is localized by said metal-dielectric structure. Delayed electromagnetic wave, which is generated by particle beam, is summarized with the field of em-beam, which is transformed on said structure, so, the particle beam influents on intensity of em-beam has observed after passing the region of localized transformation. The controlled changing of parameters of particle beam in interaction region leads to adequate changing of intensity of the em-beam passed through said region and this way the predetermined forming of electromagnetic pulses is realized. Alternatively, sequence of electromagnetic pulses is produced without initial electromagnetic beam directed to metal-dielectric structure, but due to presence of driven particle beam only.

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TERAHERTZ AND MID-INFRARED PROBING APPARATUS WITH HIGH REPETITION RATE PULSES, AND METHODS OF USING SAME

This is a continuation-in-part of co-pending U.S. Patent Application Serial Number 10/447,869 filed May 29, 2003, which is incorporated herein by reference as if fully set forth.

The present invention is directed to improved laser systems, and in particular, methods and apparatus for both the imaging an internal media for studying objects, e.g., medical imaging, and external probing of pre-surfaces region for studying objects, e.g., radar and the like.

BACKGROUND OF THE INVENTION

Vacuum electronic devices are successfully operating up to 100 GHz (wavelengths of approximately 3 mm and higher). For example, research groups that develop the high power generators of the Giroklystron type demonstrated significant progress during past several years. Optical range for these devices is up to the near-infrared band (wavelengths ~10 micron and less; frequencies ~ 30 THz and more) and they use solid-state devices including semiconductor lasers and gas powerful lasers for wave generation. The terahertz (THz) band of the electromagnetic spectrum exists between the mid-infrared band and the microwave band. Loosely defined, the terahertz band encompasses that part of the frequency spectrum that includes the frequencies ranging from about 0.3-10.0 THz, or equivalently, the wavelengths ranging from about 1.0-0.03 millimeters. In the art, the terahertz band is also known as the far-infrared band or the sub millimeter band.

The terahertz band is one of the last spectral regions where compact, powerful, coherent sources are available. High-performance terahertz-ray systems, such as periodically-probing sensors or fast-made imaging systems need robust pulsed terahertz-ray sources having tunable,

precision narrow-band, low cost means for driving the radiation power. THz (or far-infrared, or sub millimeter) and mid-infrared (3.0 – 30.0 micron) wavelength ranges are of interest both for quantum electronics and vacuum electronics developers, because there exists a lack of devices and systems that can effectively utilize these frequencies for scanning or imaging. Although the THz range is important for both civilian and military applications, there has as of yet been little implementation, however, since in many cases such applications require producing radiation having the form of a sequence of pulses with high repetition rate.

Common quantum electronics methods for the generation of mid-infrared (IR) or THz radiation are mostly based on high-energy, ultra-short laser pulses, which direct irradiating influence either on unbiased or biased solid-state (semiconductor or nonlinear) crystals. THz emission from unbiased helium gas has been reported and the first demonstration of the generation of THz radiation by photo-ionization of electrically biased air with high-energy fs-pulses has been presented.

Until recently, only thermal incoherent solid-state optical sources emitted a significant amount of light in the mid-infrared or terahertz band of the frequency spectrum. Within the last few years, several types of solid-state THz coherent optical sources have been developed for pulsed and continuous-wave applications. These THz coherent optical sources include direct coherent sources (DCS), electronically mixed electronic oscillators (EMEO), electronically mixed optical oscillators (EMOO), and optically mixed optical oscillators (OMOO). In the most successful of today's case for affordable THz crystal-emitted coherent light sources, the output power is less than 10 microwatts, while the laser pump power is about 0.1 – 1.0 W. Pump lasers have been demonstrated that produce initial radiation in the form of pulse having duration from ~ 1 nanoseconds to ~ 0.1 picoseconds, at which the repetition rate for such pulses is usually about 1 kHz. One-time pulsing pump lasers having an integration time of ~ 10 s were the first in use, while the THz signals with working at full repetition rate 64 MHz are known in the art.

THz radiation (as it shown by quantum systems' uses) can be initiated by a laser's fast pulse, and alternatively can be initiated by short relativistic electron "bunches" that produce terahertz Smith-Purcell (SP) radiation, terahertz Cherenkov radiation or terahertz wake fields – such emission takes place into the particle accelerating structures. The idea to use the radiation of fast moving electrons has been recognized by vacuum electronics developers, who try to implement an accelerator approach into a traditional microwave electronic scheme for making a

workable wavelength shorter, up to a level that produces terahertz-rays. In this manner, prior art devices such as the so-called Submillimetre-Wave Reflex Klystron, 1200 GHz Nanoklystron and several other vacuum devices have been developed during recent years.

Also, there has been recent progress in the development of the vacuum tube type Generators of Diffractive Irradiation (GDI) moving toward THz region as well as in the development of similar devices, such as the Smith-Purcell Free Electron Laser ("SP FEL"). Initially GDI were used in the millimeter band, while SP FEL had been designed for infrared band, especially. GDI and SP FEL might be joined into one generating type with near-field Cherenkov generator because all these devices use a resonance surface mode for energy exchange between relativistic electrons and a terahertz-wave. All generators of this type are called as Over-Light Speed Effect (OLSE) devices. OLSE devices (e.g., Smith-Purcell, or Cherenkov, or Diffractive, or so-called Transition Radiation) of any kind consists of charged particle radiation, when the velocity of a moving particle is higher than the speed, with which the front of electromagnetic wave is transferred (i.e., higher than the phase speed of light). Regular Free Electron Lasers (FEL), having the necessary wave generator with a very high magnetic field of sophisticated configuration are rather expensive, but SP FEL or GDI devices do not require use of such a field. Also, a regular FEL is of much larger physically as compared with GDI/SP FEL.

Klystron type generators as well as regular FELs can emit a sequence of THz pulses. For this purpose a special cathode or electron gun is used, which produces a sequence of the electron bunches. However, producing of these bunches is also rather expensive, while the repetition rate for THz pulses has not to date achieved high value in any of such generators.

Thus, although there have been advances in the prior art, to date, a system that is both robust and cost-effective has not been created. It has now been found that the current of an electron beam, which is needed to form the pulses into OLSE devices, and a robust repetition rate, which can be reached, can be created in accordance with the system of the present invention while utilizing technology known in the art, as demonstrated below.

SUMMARY OF THE INVENTION

The present invention provides methods for producing and using terahertz or infrared pulses by accelerating charged particles so as to establish a periodic positive net emission of

electromagnetic radiation. In accordance with the invention the method comprises the a manipulating means for driving accelerated particles, a transforming means for attaining the transformation of an initial em-beam into a delayed electromagnetic wave and also to provide a means for converting the kinetic energy of charged particles into an energy of the same delayed electromagnetic wave. The steps of transforming and converting take place simultaneously in the same interaction region, which has been formed by a wave-guiding structure. Said transforming means may be implemented, e.g., as said wave-guiding structure having a suitable geometric configuration and dielectric/metal properties. Said manipulating means may be implemented, e.g., as a deflector, which is driven by small voltage; alternatively, a "buncher" or other charged particles beam's properties changing system can be used for said manipulation.

Exploitation of the pulses is permits them to be directed as a sequence of pulses into the object or media being studied and analyzing the data. The pulses are detected by detecting means after passing the sequence through the object. Alternatively, data can be collected and analyzed by detecting means that register the pulses redirected (e.g., reflected, refracted, scattered, etc.) from the object or media being studied.

First, GDI was simultaneously developed with Orotron four decades ago and had very similar design. Many kinds of GDI have been proposed including metal grating on metal slab, metal grating on dielectric slab, dielectric grating on metal slab, GDI with several gratings, GDI with several electron beams, etc. Workable ideas for all of these devices consists of an exploitation of the energy exchange between the electron beam and the irradiated field, at which the exchange is provided through electromagnetic surface wave (ESW), which takes place into small spatial region near the grating. An SP FEL, which had subtle a difference with one-beam metal grating GDI has also been demonstrated. The simplest analytical expression, which satisfactorily describes a metal grating GDI or an SP FEL, is a formula for growth rate "μ", which can be written as:

$$2\mu=(4\pi/\beta\beta/\gamma\gamma)*SQRT(exp2*EM)*SQRT((i/I)/(\lambda*W)) \qquad \text{(F1)},$$

where "β"=v/c;

"c" is speed of light;

"v" is the velocity of electron cp-beam, which equals to phase speed of evanescent mode ESW;

γ - is the relativistic factor of electrons in cp-beam;

"λ" is wavelength of initial em-beam's field in free space;

"h" is the dimension of electron cp-beam in x direction (half-thickness); $h << \lambda$;

"W" is the dimension of electron cp-beam in y direction (width);

"b" - is the height of passing of electron cp-beam over the grating surface;

"l" is longitude of space in z direction, where electron cp-beam interacts with ESW of em-beam;

"i" is electric current of the cp-beam;

"I"=17kA is the Alfven current;

$exp2=exp(-(4\pi/\beta\gamma)*(b/\lambda))$;

EM – is the element of a refraction matrix of the metal grating, which provides the "quality" of coupling between electromagnetic field and electron cp-beam. In the optimal case this formula takes exp2*EM=~0.1. and has satisfactory correspondence with most experimental data.

A device is also known which uses ESW over the dielectric grating in the case of total internal reflection using a resonance transformation of a spatial wave into ESW by a Grating Cherenkov Scheme (GCS) described by a formula, which is similar to (F1), but EM is changed to ED – the element of refraction matrix of the dielectric grating. In the optimal case ED can reach ~1.0, i.e., the "quality" of the coupling between electromagnetic field and electron beam over the dielectric grating can be up to several times more than over the metal grating. The main reason which explains this fact, isthat GCS uses a single mode regime of field versus two modes regime (at least) in metal grating GDI/SP FEL.

Analysis of threshold currents for metal grating GDI/SP FELs is made in the numeric example, when kinetic energy of electrons is equal to 32keV and phase velocity of ESW is equal to $\beta=v/c=0.34$. Longitude of the interaction region "l" is squeezed up to the accessible limit, which is determined by the minimum possible diameter of gauss optical beam and equals to multiple of tens of optical wavelengths, e.g., $l=10m\lambda$, where m – is a small integer. It is necessary for modulation to reach the growth of intensity of optical beam up to 100a percent after passing through the interaction region; a – is a small rational number, i.e., a<<1 and it is typically $2\mu l=a$. If the electron beam is squeezed up to $h=0.1\lambda$ and $W=100h=10\lambda$, and the "quality" of coupling between optical field and electron beam is optimal, then from (F1) the formula for necessary

current in GDI/SP FEL is approximately obtained as $i=1.78a*a/(m*m)$ Amp. As it's seen from this formula the 13% gain ($a=0.13$ is enough for smooth modulation purpose) after passing $l=30\lambda$ (e.g. $m=3$) will be reached, if GDI/SP FEL has a current $i=3.3$ milliamp. So, the necessary current of a metal grating GDI is approximately equal to necessary current of SP FEL; however, at the same time the necessary current of resonance GCS is significantly less (~0.3 milliamp), because an optimal GCS has the best "quality" of coupling between the optical field and the electron beam.

Of course, for the forming pulses the modulation should be greater than in mentioned-above numerical example. It means that a case where $a=0.13$ is not enough for pulse forming, but it should instead be a case where $a=0.90$, approximately. For last case the numerical calculation of the necessary threshold current is much more difficult than in the case of smooth modulation, but the same conclusion is true: the calculated necessary current, which is needed for forming pulses by resonance GCS, is considerably less than calculated threshold current of metal grating GDI/ SP FEL. However, it is known in the art that the generation process by SP FEL is started for a threshold current, which is three times less, than Kim's theory or any other theory predicts. So, both GCS and GDI/SP FEL might be considered useful for purpose of effective forming the THz pulses by a scheme having reasonable value of electron current.

The time of interaction between transformed em-beam field and electron cp-beam approximately equals $t=l/v=10m*\lambda/(\beta c)=10m/(\beta\omega)$, where ω is a frequency of field of em-beam. Consequently, the frequency of modulation of em-beam by electron beam can approximately reach:

$$\Omega=1/nt=\beta\omega/10nm \qquad \text{(F2)},$$

where "n" is the so-called coefficient of packing, which shows the ratio of a rather long non-modulated (or without-pulses) period to the time of interaction (when pulse is sharply appeared, existed and decreased). To be verify these results, we can rewrite:

$$\Omega < \Omega R \sim 0.001\ \omega = 0.1\ \%\ \omega \qquad \text{(F3)},$$

where ΩR is the robust maximum of frequency of modulation which can be reached.

The using of formula (F3) for ΩR means that, for example, 1 THz continue wave beam might be separated into the sequence of t-pulses with repetition rate equaled to 1 GHz, while for mid-infrared case having λ=30 micron (or ω = 10 THz) it might be achieved the sequence of quasi-pulses with repetition rate near 10 GHz. Both 1 GHz and 10 GHz are quite appropriate repetition rate to be registered by the fastest modern detectors of THz radiation .

As it follows from F2, the theoretically predictable absolute maximum for repetition rate ΩA might be calculated, if $\beta = 0.9$, $m = 1$ and $n = 2$ (relativistic electron beam is used for modulation, while optical beam is squeezed up to 10 λ and the without-pulses period is equal to a time of interaction). Such ΩA approximately defines as $\omega / 20$ and equals up to 500 GHz for mid-infrared region. However, the registration of so fast 500 GHz repetition rate is not achievable by mid-infrared detectors, which have been developed until now

DESCRIPTION OF THE PREFERRED EMBODIEMNTS

An effective manipulating means can be implemented into OLSE emitting scheme and this way the ultra-high repetition rate sequence of THz pulses can be formed.

In the case of using of ESW, the interaction region has effective longitude "l" and height ~(b + h), at which interaction takes place exactly at the time when the optical field, which should be modulated, and the electron beam, which provides modulation, are simultaneously present at said region. Controlled modulation of the optical field is able to be reached by changing the parameters of the interacting electron beam. In particular, before the process of interacting the electron beam is able to be changed by at least two methods: 1) by bunching (making discrete density) of electron beam without changing its propagating direction; and 2) by deflection of the electron beam from interaction region and returning to said region without changing the current density. As far as first method is concerned, today's FEL / Particle Accelerator technique operates by relativistic flat electron bunch having parameters, for example, such as h=0.5μm, W=50.0μm, l=30μm, and i =100kA; as known in the art, an electron bunch can be squeezed up to a value of h that is approximately tens of angstrom and a value of l/c that is approximately tens of an atto-second. Such bunching is over and above, than what is needed for optical modulation, however making such a bunch is very expensive at the present time. As a second method, it is can be shown that a simple pair of flat electrodes is able to provide the necessary deflection/returning of the electron beam by using a voltage not very much more than ~1V. It is

well-known if the axis of the electron beam is in the middle between two parallel flat electrodes when said electrodes have no voltage, than the switching on voltage "U" provides deflection of electron beam, which, in beginning of observation region said deflection "d" is proportionally d $\sim(U/\gamma/\beta\beta)*L1*(0.5L1+L2)/R$, where L1 is length of electrode, L2 is a distance from electrode to observation region, R is a distance between electrodes. So, if a pair of deflecting electrodes is interposed before interaction region (which coincides with observation region) and, for example, $\beta=0.34$, $L1=30\lambda$, $R=4h=0.4\lambda$, $L2=m2*10\lambda$, m2 is integer, than d is approximately equal $d=1.25*(1.5+m2)*\lambda*abs(U)/100$, where abs(U) is absolute value of U and U should be taken in volts. Taking m2=7 previous formula gives $d=0.1*abs(U)*\lambda=abs(U)*h$ and it shows the possibility of a simple system for manipulating an electron beam into an interaction region. Said manipulating is preferably achieved by a small voltage, because if electron beam is deflected up to some "h" superfluously over conducting ESW surface, then interaction practically ceases. Hence, the changing of deflecting electrodes' voltage from zero to "U" leads to modulation of optical field and said modulation has the same frequency as the frequency of the voltage changing. Also for realizing the second method, the deflector can be made as a standard magneto-deflecting system, which has a small manipulating magnetic field. Both a flat-electrodes deflector system and a magnetic one or, other similar deflecting systems do not have problems in modern technical realization, and obviously, they won't be expensive.

If for modulating light producing a Smith-Purcell, or Cherenkov, or Transition Radiation effect, or any combination of OLSE effects are used, then the interaction region will be small as well as in previous example, and the simple manipulation by free moving electrons is going to provide the necessary modulation process, as shown above.

Applying of a voltage from a saw-tooth oscillator to deflecting electrodes will provide predictable manipulation of the electron beam and this is the way the necessary sequence of pulses is formed. Having, for example, a periodically energized 1 GHz saw-tooth oscillator, the same repetition rate is achieved for a formed sequence, while the irradiated field will be of terahertz band. Such periodical driving means are constructed at present, for example, in vacuum tube type electron guns, found in computer monitors .
Therefore, two kinds of the forming of THz pulses should be separated from each other: 1) deep modulation of initial terahertz continuous wave; 2) directly producing terahertz pulse sequences without an initial continuous wave.

Referring now to the drawings, FIG. 1 is a schematic diagram of a preferred embodiment of the invention. The charged particle beam 1 is typically composed, for example, of electrons. Said beam is irradiated by the accelerating system 2, directed to the manipulating system 3, and after that directed to the transforming system 4. Optical beam 5, which should preferably be modulated, is also directed to the transforming system 4. Manipulating system 3 can be of bunching type, or of deflecting type (by electric field or by magnetic field, or by combination of such fields), or, may be of another type for changing the properties of the charged particle beam. Transforming system 4 can be of UOA type, or of FEL type, or of LAC type, or of other one from the full set of OLSE-type combinations. After passing through the transforming system 4 the modulated optical beam propagates in free space up to the distant detector 6; alternatively the transforming system 4 turns into fiber optic transmitting line 7. Therefore, such a method of modulation can be exploited for both free space communication (when modulated laser beam 51 is transmitted, for example, directly to satellite receiver or retranslator) and for fiber optic communication (when modulated optical signal 52 is transmitted through a dielectric optical wave-guide).

Various changes to the foregoing embodiments of the present invention would now be evident to those skilled in the art. Accordingly, the particularly disclosed scope of the invention is set forth in the following claims. In view of the invention disclosed, the idea of the manipulation of an accelerated particle beam for creation controlled light modulators is quite workable now and can be realized in many different cases. As well as it is known said idea has never been published earlier, but modulators, which are based on this idea, will provide much more speed of modulation than previous ones. Additional reasons related to the usefulness of OLSE-modulator are disclosed herein. Nuclear weapons have for five generations been the main effect consisting in electromagnetic radiation (EMR). EMR is supposed to influence semiconductor elements the way that they will change their properties and after EMR influences the devices which contain said elements, the devices will typically malfunction. At the same time devices without semiconductor elements, for example vacuum tube type, do not malfunction after EMR influence. That's why the OLSE-type modulator, which does not have any semiconductor element, has a very important positive difference from electro-absorption modulators, which are made of semiconductor material.

FIG. 2 is a schematic diagram of a longitudinal section of a preferred embodiment. The ribbon electron beam 1 (e-beam) is preliminarily accelerated up to velocity $v/c=\beta$ and is directed to the manipulating element 12 which is preferably of the deflecting flat electrodes' type (deflector), which is separated by a distance L2 from the OLSE-transforming element 23 of the

dielectric spatially periodical wave-guiding structure type (transformer). Deflector 12 and transformer 23 are in a vacuum vessel 4 which is also illustrated schematically and is shown with a broken away portion allowing the components discussed immediately above to be viewed..

Having elliptical midplane the optical beam 5 (o-beam) with wavelength λ is normally directed to optical input surface 13 of transformer 23; at that, o-beam's electric field is parallel to the plane of longitudinal section. Transformer 23 is made of dielectric with refractive index n and has two surfaces – plane surface 13 for o-beam inputting and periodically ribbed surface 14 having period Λ; the angle between these surfaces is equal to α. At that, for optimal functioning two obligatory conditions must take place together:

$$\lambda/\Lambda = n * \sin(\alpha) = (c/v) > 1$$

E-beam is of ribbon type having small half-thickness h and width W, for example, W=100h, and β=0.34.

O-beam is supposed to have oval projection on the surface 14, for example, having longitude l=30λ. Deflector 20 consists of two flat parallel electrodes 21 and 22 each having longitude L1; the distance between said electrodes equals R, for example, R=4h. The applied voltage between the deflector's electrodes can be changed from 0 to U volts. If said voltage equals 0, then the e-beam moves in the middle plane between electrodes without deflection. If said voltage equals U, then the e-beam is deflected from said middle plane and the total deflection equals d after passing through the L1-length of deflector and L2-length between deflector and transformer.

When the e-beam passes thorough the deflector element 2 without deflection (voltage equals 0), then the trajectory 8 of e-beam is parallel to the ribbed surface 14 and has a height b over said surface. When the deflector's voltage equals U, then the trajectory 9 of the e-beam has a height not less than b +d over the ribbed surface 14.

If, for example, L1=30λ and L2=70λ, then d is approximately equal to d=abs (U)*h. Compared to non-deflecting trajectory 8, deflecting trajectory 9 of the e-beam has additional decreasing of coupling with the optical field, which is modulated, and said decreasing is in proportion to exp ($2\pi d/\lambda\beta\gamma$). So, if, for example, d equals d=0.1λ (i.e., U=1 volts and h=0.1λ), then in this example said coupling on the deflecting trajectory is up to six times less than coupling on the non-deflecting trajectory.

Ribbed surface 14, for example, has a ribbed profile; the dimensions of the ribs are determined to provide optimal value of the fundamental mode of a refraction matrix of said periodically ribbed surface. It is necessary for minimizing the value of current of e-beam, which

is enough to provide modulation. However, even though the ribs have zero length and zero height (e.g., ribbed surface 14 is flat), then modulating effect can be reached too, but by using of considerably more value of the current of the e-beam than in the case of optimal profile. At that, the use of flat surface has important advantage – it is much more simple to go about making such a surface.

EXAMPLES

A sequence of terahertz pulses is useful both for 1) the exploration of the internal media of objects and 2) the external describing of objects. In first case the pulses are directed into an object and information is collected and analyzed the collection of data being performed by a detecting means after passing the sequence through said object. In second case, information is again analyzed by detecting means, but in this case the pulses that are collected are redirected from a surface of the object being studied. The first-type of use might be applicable for diagnosing the characteristics of plasma, biomedical probing and imaging in security systems, while the second-type of usage is typical for the needs of radar, sonar and similar systems. At the same time, both uses can be implemented for other practical applications including industrial process control, nondestructive testing and so on.

It is known that for THz-frequencies the plasma acts as a nearly transparent dielectric, with refractive index close to unity. Analysis of the dispersion and attenuation of terahertz pulses passing through studying media will enable properties of the plasma (collisional damping, electron density) to be characterized in an adequate manner . More comprehensive information might be received, if the high repetition rate sequences of terahertz pulses passing through plasma are analyzed.

Imaging of terahertz radiation represents an emerging technology with significant potential for advanced, security-related inspection systems. Terahertz radiation is transmitted by many visually opaque objects and materials but reflected by others, permitting complementary imaging in transmissive and reflective modes. Many potentially harmful gases and other chemicals exhibit distinctive spectral fingerprints in the terahertz region. Together these characteristics permit terahertz radiation-based discrimination between harmful and innocuous objects, materials, and chemicals concealed in packages and on personnel through the use of safe, low-power, non-ionizing radiation with no real or perceived health risks .

As noted above, the use of high repetition rate sequence of terahertz radiation pulses opens the possibility of considerably improving a radar system's sensitivity, target detection, discrimination and aimpoint selection . Such THz and mid-infrared radar related technologies and the associated processing techniques are useful both for military purposes and commercial ones.

By combining the approaches which have been above, those of skill in the art will appreciate that the present invention also provides a set of sensors for medical and bioscience applications.

ABSTRACT

An apparatus for producing the sequence of Terahertz electromagnetic pulses by driven particle beam is disclosed. Initial electromagnetic beam (em-beam) is being sent to metal-dielectric structure the way that the field of said em-beam partially transforms into delayed electromagnetic wave, in preferred embodiment into the surface evanescent mode, and the beam of charged particles (cp-beam), in preferred embodiment electrons, is also being sent to said structure the way that the particles' kinetic energy partially transforms into energy of the delayed electromagnetic wave having the same phase-frequency's characteristics as transformed field of em-beam; at that, transformation of em-beam and excitation of wave by particles' cp-beam commonly take place at the same small space region, which is localized by said metal-dielectric structure. Delayed electromagnetic wave, which is generated by particle beam, is summarized with the field of em-beam, which is transformed on said structure, so, the particle beam influents on intensity of em-beam has observed after passing the region of localized transformation. The controlled changing of parameters of particle beam in interaction region leads to adequate changing of intensity of the em-beam passed through said region and this way the predetermined forming of electromagnetic pulses is realized. Alternatively, sequence of electromagnetic pulses is produced without initial electromagnetic beam directed to metal-dielectric structure, but due to presence of driven particle beam only.

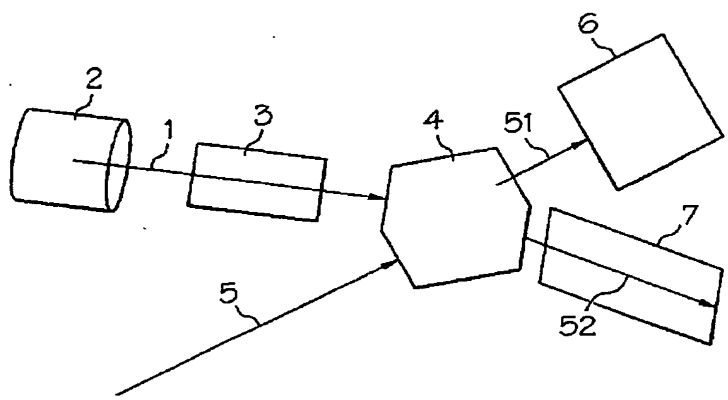

FIG. 1

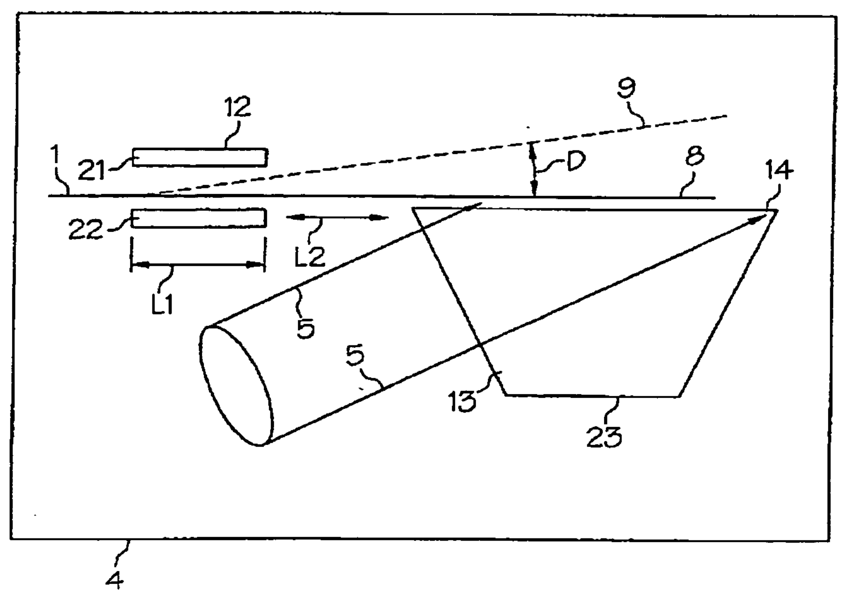

FIG. 2